CCD OBSERVATIONS OF THE RR LYRAE VARIABLES IN THE GLOBULAR CLUSTER NGC 5897

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ABSTRACT

CCD observations for 10 (6 previously known and 4 newly discovered) of the 11 RR Lyrae variables in NGC 5897 have been analysed. The period-luminosity and period-amplitude plots indicate that the population of RR Lyrae variables in NGC 5897 includes 3 fundamental mode, 4 first-overtone and 4 second-overtone variables with mean periods $0^{\mathrm{d}}.828$, $0^{\mathrm{d}}.459$ and $0^{\mathrm{d}}.343$ respectively. The variables have properties that are similar to some of the Oosterhoff type II variables in ω Centauri. Two of the new variables (V11 and V13) were previously considered to be possible non-variables that lie within or near the instability strip on the horizontal branch; both have V amplitudes less than 0.2 mag. There is a chance that one or two of the variables (V10 and possibly V3) might be anomalous Cepheids and not RR Lyrae stars.

Subject headings: globular clusters: individual (NGC 5897) — stars: fundamental parameters — stars: horizontal-branch — stars: variables: RR Lyrae

1. INTRODUCTION

NGC 5897 (C1514-208) is a moderately metal poor globular cluster with [Fe/H] = −1.80 (Harris 1996). Color-magnitude diagrams for NGC 5897 have been published by Sandage & Katem (1968, hereafter SK), Ferraro et al. (1992), Sarajedini (1992) and Testa

et al. (2001) and all of them show that the horizontal branch is predominantly blue. The cluster has nine known variable stars: seven RR Lyrae (Wehlau 1990, hereafter W90), one red variable (Eggen 1972) and one SX Phe (Wehlau et al. 1996). W90 has shown that the RR Lyrae variables have a very unusual period distribution; three have periods between $0^{d}.797$ and $0^{d}.856$, two at $0^{d}.420$ and $0^{d}.454$ and two more at $0^{d}.342$ and $0^{d}.349$. As a result, the mean period of the three RRab variables is $0^{d}.828$. The fact that the periods of the RRab variables in NGC 5897 are longer than $0^{d}.60$ is not unusual because Clement et al. (2001) have shown that for all clusters more metal poor than -1.70, the mean period of the RRab stars is greater than $0^{d}.60$. What is unusual, however, is that $< P_{ab} >$ is greater than $0^{d}.80$; the next longest $< P_{ab} >$ for a metal poor cluster is $0^{d}.708$ for NGC 4833 which has [Fe/H]$= -1.79$.[1]

Another curious feature of NGC 5897 is the fact that there appear to be nonvariable horizontal branch stars located in its RR Lyrae gap. Both SK and W90 have shown that the stars SK 116 and SK 174 have colors and magnitudes comparable to the RRc stars and that SK 120 lies in the instability strip well to the red of the RRc stars and to the blue of the RRab stars. Smith (1985) made a spectroscopic study of SK 120 and concluded that the star is probably a cluster member. We therefore decided it would be worthwhile to observe NGC 5897 with a CCD detector. It may turn out that some of these 'apparent' nonvariable stars are in fact varying, but with an amplitude lower than can be readily detected in photographic studies. All of the published photometric studies of the RR Lyrae variables in NGC 5897, with the exception of a set of CCD observations of V2 by Wehlau et al. (1996), are based on photographic data.

2. THE OBSERVATIONS

Our investigation is based on 526 CCD frames obtained with the University of Toronto's 61 cm ($f/15$) Helen Sawyer Hogg (HSH) telescope at the Las Campanas Observatory of the Carnegie Institution of Washington. The observations were made on six consecutive nights (May 1 to 6, 1997) with the Kodak KAF-4200 CCD system that Horch *et al.* (1997) and Slawson *et al.* (1999) used with the same telescope in February 1997. The chip has 9 μm square pixels arranged in a 2033×2048 format, but before readout, the data were

[1]Generally, the RR Lyrae variables in metal poor clusters have longer periods than the ones in metal rich clusters. However, Pritzl et al. (2000) have recently shown that the two metal rich clusters NGC 6388 and NGC 6441 have $< P_{ab} >$ of $0^{d}.71$ and $0^{d}.76$, respectively, for their RR Lyrae variables. The variables in these two clusters seem to be brighter than solar neighbourhood field RR Lyrae stars of comparable [Fe/H], but the reason for this is not yet fully understood.

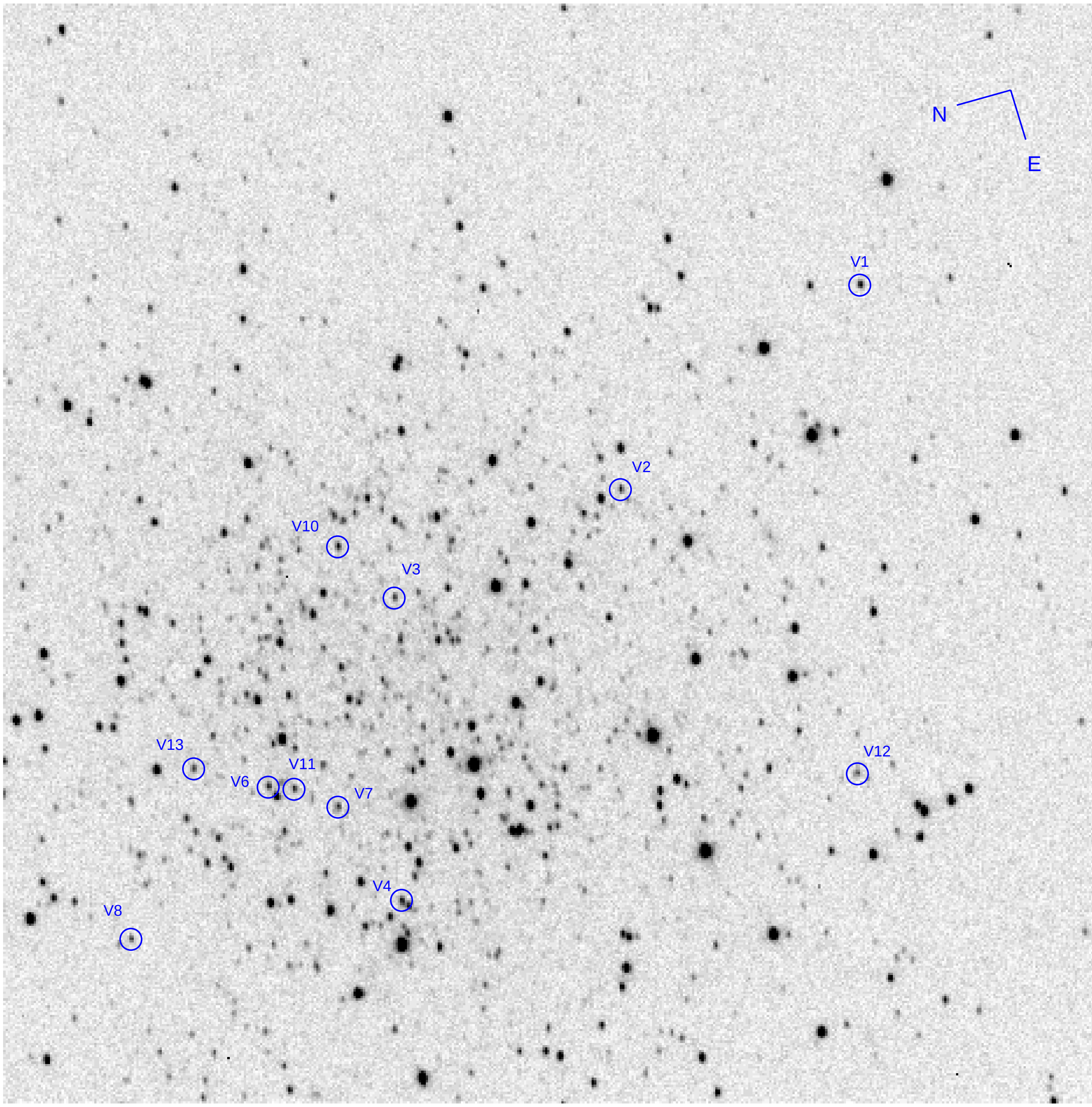

Fig. 1.— Identification chart for the RR Lyrae variables in NGC 5897. The field of view is 6.9×6.9 arcminutes. V1-4, 6-8 and 10-13 are labelled. West is at the top and north on the left.

binned 2×2 so that the effective pixel size for our data was 18 μm square. The field of view (shown in Figure 1) is approximately 6.9×6.9 arcminutes and includes all of the RR Lyrae variables studied by W90. The frames were obtained through a V filter and all of the exposure times were 2 minutes. These short exposures were necessary because of severe tracking problems with the telescope.

The frames were cleaned using IRAF. Then, for the photometric reductions, we combined the frames in groups of three, so that we could obtain photometry with a precision of 0.02 mag (or better) at V$\sim$ 16.5, the level of the horizontal branch. In Table 1, we list a sample of the data obtained on the night of May 1 to illustrate how the frames were combined. The photometric reductions were carried out using the IRAF versions of DAOPhot-II and ALLSTAR-II and the stand-alone version of Stetson's (1987, 1993, 1994) ALLFRAME code. Approximately 1000 stars were identified on each frame.

In order to convert our instrumental magnitudes to standard V magnitudes, we used the photometry of SK. Since none of their photoelectric standards were in the field shown in Figure 1, we obtained 7 frames on the night of May 4 with the telescope offset to a position 5.7 arcminutes further north. With this offset, we were able to include the SK photoelectric standard stars A, C, E, K, M, N, O and P in the field of view. We determined the instrumental magnitudes for the stars that were in the area overlapping the two fields on the same magnitude scale as the 'offset' frames and then calculated magnitudes on the same scale for all of the program stars. Finally, the transformation from instrumental to standard V magnitudes was derived for SK's photoelectic standards and then applied to all of the other stars.

3. THE VARIABLES

3.1. Search for Variables and Period Determination

The known RR Lyrae variables were identified and found to have a mean V magnitude of $\sim$ 16.25. To search for additional RR Lyrae variables, we examined the observations for all of the stars with mean V magnitude between 15.75 and 16.75 (approximately 150 stars). We plotted light curves to check for periodic variations. As a result, four new RR Lyrae variables were identified. We have numbered them V10 to V13 and they are labelled in Figure 1. This increases the total number of known RR Lyrae variables in NGC 5897 from seven to eleven. In order to determine the periods for the new variables, we used Stellingwerf's (1978) phase dispersion minimization technique to estimate an approximate value and then made small adjustments so that the observations for the different nights

would be well aligned. Our adopted periods are listed in Table 2. For the known variables, we adopted the periods listed by W90. Also included in the table are the SK number, the x,y position on the frame in pixels, the x,y position relative to the cluster center in arcseconds on the system of Sawyer Hogg (1973), the mean V magnitude, the V amplitude along with the standard deviation of the fit to equation (1) and the Fourier phase differences ϕ_{21}, ϕ_{31} along with their standard errors. The mean magnitudes and amplitudes were derived from a fit to a Fourier series of the form:

$$mag = A_0 + \sum_{j=1,n} A_j \cos(j\omega t + \phi_j) \tag{1}$$

where ω is (2π/period). The Fourier phase differences (ϕ_{ji}) are ($\phi_j - j\phi_i$) from equation (1). For each star, the epoch was taken as HJD $2,450,500$ so that t in the equation refers to (HJD$-2,450,500$) and HJD represents the mean heliocentric Julian date of the observation (in this case, the combination of three frames). Light curves, arranged in order of increasing period, are shown in Figure 2. A sample of the observations for V1 is shown in Table 3. All of the observations for V1-3, V6-8 and V10-13 are presented in the electronic version of the table. V4 was not included in our study because its image was blended with that of another star and as a result we were unable to obtain photometry with the desired precision. In fact, many of the frames could not be used to study the other variables either, because of the tracking problems.

It turns out that two of the new variables, V11 and V13 are SK 120 and SK 116 respectively, apparent nonvariable stars that lie in or near the RR Lyrae gap according to SK and W90. Since the V amplitudes for these two stars are less than 0.20 mag, they were not detected in photographic studies of the cluster. We also examined the magnitudes for SK 174, a star that W90 found to be near the blue edge of the instability strip, but no systematic variation was detected. Its mean V magnitude is 16.392 with a standard deviation of 0.029. In comparison, the standard deviation of the previously known variables

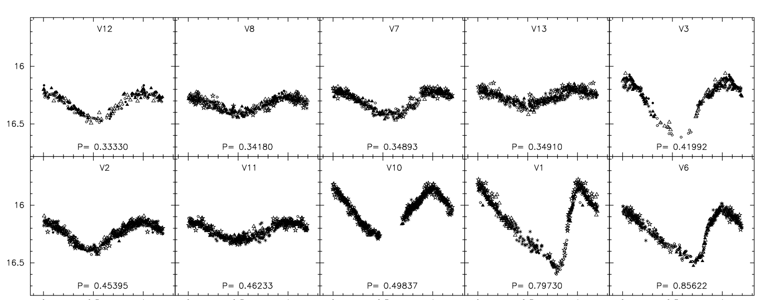

Fig. 2.— V light curves for the 10 stars in our sample. The curves are arranged in order of increasing period.

ranged from 0.053 for V8 to 0.215 for V1.

The other two new variables, V10 and V12, have larger amplitudes, but their periods are close to simple fractions of a day. This probably accounts for the fact that they were not discovered previously. In fact, even in the present study, the phase coverage for V10 (P$\sim$0$^{\rm d}\!\!.$5) is incomplete. We considered the possibility that V10 has a period twice as long, but concluded this to be unlikely. The shape of its light curve is similar to that of three ω Centauri variables with similar periods, V47, V68 and V123 (OGLE ID 185, 73 and 169), observed by Kaluzny et al. (1997, hereafter K97). All of these stars have an inflection on the rising branch of their light curves, just before maximum light. Furthermore, the ω Cen stars for which K97 found periods of about 1 day are all more than 0.5 mag brighter than the RR Lyrae variables. Since V10 is only 0.2 magnitudes brighter than the mean $< V >$ for the other variables, we assume that our adopted period is the correct one.

3.2. Period-Luminosity and Period-Amplitude Relations

The period-luminosity and period-amplitude relations are plotted in Figure 3. In the upper panel of the diagram, the stars separate into three separate regions which we interprete to be due to different modes of pulsation: fundamental, first and second-overtone. W90 has already noted that the variables with periods $\sim$0$^{\rm d}\!\!.$34 may be pulsating in the second-overtone mode. Another interesting feature of Figure 3 is its similarity to the P-L and P-A plots that Clement & Rowe (2000, hereafter CR) made for the ω Centauri variables observed by K97. To illustrate this, we plot in Figure 4 the Fourier phase differences ϕ_{21}, ϕ_{31} and the V amplitude against $\log P$ for the NGC 5897 variables and include the ω Cen variables that CR considered to belong to the Oosterhoff (1939, 1944) type II class (i.e. $< V > \leq 14.65$ for the fundamental mode and $< V > \leq 14.60$ for the overtone modes). Also included is star 96 ($\log P = -0.3$, $A_V = 0.17$) of K97 which was not included in CR's study.

In Figure 4, it can be readily seen that the RRab stars V1 and V6 have periods, Fourier phase differences and amplitudes comparable to some of the ω Cen Oosterhoff type II fundamental mode pulsators. What is striking though is that V1 and V6 have longer periods and hence lower amplitudes than most of the ω Cen stars. A similar trend can be seen among the first-overtone variables. Both V2 and V11, with periods $\sim$0$^{\rm d}\!\!.$46 ($\log P \sim -0.34$), have much lower amplitudes than most of the ω Cen first-overtone pulsators. The case of V2 is particularly interesting because W90 found an increase in period and a decrease in amplitude for this star between the 1950s and the 1980s. The V amplitude we have derived for V2 (0.24 mag) is comparable to her lower, more recent value (0.22 mag), but the V amplitude that she derived for the 1956-1966 observations was 0.39 mag, similar to the

amplitudes of the ω Cen first-overtone variables. V2 seems to have changed significantly during the last 50 years. We analysed our observations to search for evidence that V2 is in the process of mode switching. To do this, we measured the residuals to the light curve and searched for periods in the range between $0^{\mathrm{d}}.25$ and $0^{\mathrm{d}}.65$. No oscillations with an amplitude greater than 0.03 mag were detected for any period in the interval. If the star were in the process of changing from first-overtone to fundamental mode pulsation, we would have expected to detect oscillations with a period $\sim 0^{\mathrm{d}}.60$. We therefore conclude that if V2 is in the process of switching modes, the fundamental mode oscillations are still very weak.

The four stars with P$\sim 0^{\mathrm{d}}.34$ (V7, V8, V12 and V13) have periods and amplitudes comparable to some of the ω Cen second-overtone variables, but, like the RRab stars, they seem to congregate at the long period end of the sequence in the P-A plot. CR found that several of the second-overtone variables in ω Cen exhibited non-radial pulsations. We performed a period search on the residuals to the light curves of the above-mentioned four stars in an attempt to search for non-radial pulsations. No oscillations with amplitudes greater than 0.03 mag were detected in any of them. However, the amplitude of the non-radial pulsation detected by CR for star 186 in ω Cen was 0.10 mag, much higher than this.

As noted previously, the light curve for V10 has a structure similar to the light curves of V47, V68 and V123 in ω Cen and we suggest that it might be an anomalous Cepheid. The properties of anomalous Cepheids (ACs) have been discussed by Nemec et al. (1994, hereafter N94). They are located in the Cepheid instability strip and are more luminous than horizontal branch stars, but they tend to have shorter periods than globular cluster Cepheids because they are more massive. They are probably coalesced binary stars and may be related to blue stragglers. Most of the known ACs occur in nearby dwarf galaxies, but N94 pointed out that V68 in ω Cen might be an AC pulsating in the fundamental mode.[2] We assume that if V68 is an AC, then V47 and V123 in ω Cen should also be classified as ACs and if clusters with blue stragglers are more likely to contain ACs, then it is plausible that there are ACs in NGC 5897 as well. Testa et al. (2001) pointed out that the cluster has a sparse, but clearly visible population of blue stragglers. If V10 is an AC, then V3 could be one as well. N94 derived a slope for the period luminosity relation for AC variables: $\Delta V/\Delta \log P = -3.13 \pm 0.28$ and if both V3 and V10 are ACs, V3 should be 0.23 mag fainter than V10. The actual difference is 0.27 mag, in reasonable agreement with the prediction of N94. Another possibility raised by N94 is that stars like this might be first-overtone population II Cepheids. Thus, there is still some doubt about the true nature

[2]N94 also considered that V84 in ω Cen might be an AC candidate, but in the meantime, van Leeuwen et al. (2000) have shown that V84 is not a member of ω Cen.

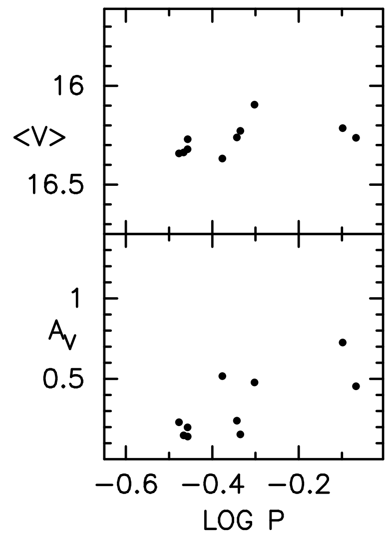

Fig. 3.— The period-luminosity and period-amplitude relation ($< V >$ and A_V versus $\log P$) for the RR Lyrae variables in NGC 5897.

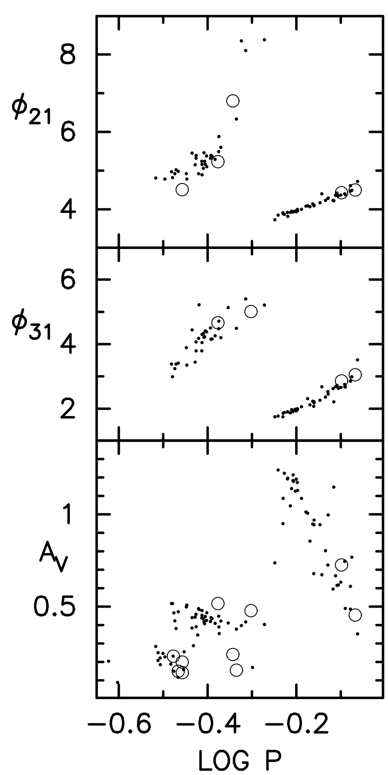

Fig. 4.— Plots of ϕ_{21}, ϕ_{31} and A_V versus $\log P$ for the RR Lyrae variables in NGC 5897 (open circles) and the Oosterhoff type II RR Lyrae variables in ω Centauri (dots). Values for ϕ_{21} and ϕ_{31} are plotted only for stars for which the error is less than 0.2.

of V3 and V10.

Our study reinforces the conclusion that the period distribution of the RR Lyrae variables in NGC 5897 is unusual. W90 plotted a period-frequency distribution that demonstrated that the cluster has no variables with periods between $0^{\rm d}\!.45$ and $0^{\rm d}\!.75$ where the majority of RRab variables are found in other clusters. Although we have discovered four new variables in this investigation, and two of them have periods between $0^{\rm d}\!.45$ and $0^{\rm d}\!.50$, neither is an RRab star. Furthermore, there are still no known variables with periods between $0^{\rm d}\!.50$ and $0^{\rm d}\!.75$ and most cluster RRab stars have periods in this range.

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Table 1. A Sample of the Observations Obtained on May 1

Frame #1	Frame #2	Frame #3	Combined Frame #	mean Hel. JD
971095	971096	971097	may01add01	2450570.5335
971096	971097	971098	may01add02	2450570.5373
971097	971098	971099	may01add03	2450570.5410
971098	971099	971100	may01add04	2450570.5439
971099	971100	971101	may01add05	2450570.5466
971100	971101	971102	may01add06	2450570.5495

Table 2. The RR Lyrae Variables in NGC 5897

Var #	SK #	x (pix)	y (pix)	x"	y"	Period (days)	$< V >$	$A_V(\sigma)$	$\phi_{21}(\sigma)$	$\phi_{21}(\sigma)$
1	351	125	688	-109	-201	0.797296	16.21	0.73 (0.034)	4.43 (0.04)	2.86 (0.05)
2	299	347	498	-57	-97	0.453945	16.26	0.24 (0.024)	6.80 (0.17)	5.97 (0.49)
3	206	556	397	-40	-4	0.419917	16.37	0.52 (0.026)	5.23 (0.19)	4.66 (0.17)
4		549	116	+71	+20	0.83127	—	—	—	—
6	118	673	221	+16	+59	0.856223	16.26	0.45 (0.026)	4.50 (0.04)	3.05 (0.08)
7	161	608	203	+31	+35	0.348931	16.32	0.20 (0.024)	4.51 (0.18)	2.73 (0.34)
8	63	800	80	+58	+122	0.341802	16.34	0.15 (0.025)	4.59 (0.51)	6.78 (0.56)
10	177	609	444	-64	+12	0.49837	16.10	0.48 (0.022)	4.45 (0.26)	5.01 (0.09)
11	120	649	219	+20	+49	0.46233	16.23	0.16 (0.025)	2.60 (0.21)	7.70 (0.61)
12		127	235	+70	-158	0.3333	16.34	0.23 (0.024)	5.38 (0.41)	4.49 (0.75)
13	116	742	238	+2	+84	0.3491	16.27	0.14 (0.029)	1.61 (1.17)	6.71 (0.63)

Table 3. Observations for V1

Mean Hel. JD -2,450,500	V
70.665	16.410
70.673	16.405
70.680	16.394
70.685	16.415
70.779	16.491
71.548	16.459
71.564	16.439
71.568	16.442